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13. ABSTRACT
Summarizes work performed in 1995 by Summus Ltd. for McDonnell Douglas Aerospace under the ARPA University-Industry ATR Initiative. The focus of this work is on the use of wavelets and non-linear partial differential equations to extract features to separate targets from clutter in sensor imagery.

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MULTIRESOLUTION APPROACHES FOR AUTOMATIC TARGET DETECTION / RECOGNITION / IDENTIFICATION

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Multiresolution Approaches for Automatic Target Detection / Recognition / Identification

Progress Report: Year 1

SUMMUS, Ltd.

February 19, 1996

The following is a summary of work performed in 1995 by Summus Ltd. on a subcontract from McDonnell Douglas Aerospace under the ARPA Automatic Target Detection/Recognition/Identification contract. Portions of this work are also being supported by ONR and two graduate students in the Industry Research Graduate Traineeship (IGRT) program through NSF.

1 Target / Clutter Characterization

We have designed and implemented a new algorithm for separation of targets from background clutter in static images. The algorithm uses a wavelet-based oscillation measure which characterizes the texture properties of the image. The oscillation measure is calculated as a weighted sum of the wavelet coefficients and the DC component coefficients over a varying neighborhood.

A particular example of this type of oscillation measure provides the "fractal signature" of the underlying texture. The fractal signature is calculated from the local fractal dimension within the γ wavelet coefficient spaces, in essence treating the multichannel texture, that is associated with clutter, as an n-dimensional surface, that can be used as a decision aid or feature for other algorithms.

$$dim(graphf) = \overline{\lim_{\nu\to\infty}} \frac{log^{+} \sum_{|I|=2^{-\nu}} |I|^{-1/2} |(S_{\Phi}f)_I|}{log^{+} 2^{\nu}} + 1,$$

where $(S_{\Phi}f)_I$ is the wavelet transform of the function f for dyadic I.

For automatic target detection, we have also designed and implemented a quadtree based image segmentation algorithm. The algorithm gives a partitioning of the input image into homogeneous regions based, for example, on pixel intensity. The image segmentation algorithm can be applied to the image itself or it can be combined with the above target/clutter separartion algorithm for automatic target recognition.

The algorithms have been implemented in C with graphical user interface in X-windows and OSF/Motif and in a digital signal processor (Texas Instruments C40).

2 Feature Enhancement Techniques

Summus, Ltd., is investigating several feature extraction techiques to improve the capability to perform feature extraction for automatic target detection/recognition/identification, and general image quality. We are concentrating on two areas:

- Feature Enhancement and Extraction in the Wavelet Domain
- Feature Enhancement and Extraction Using Linear/Non-linear PDEs

2.1 Feature Enhancement and Extraction in the Wavelet Domain

We have developed new methods for feature enhancement and extraction in the wavelet domain by applying the conventional highpass filters based on 3x3 or 5x5 pixel neighborhoods, such as a Laplacian or a Gaussian filter, in the wavelet domain. We have selected a bi-orthogonal wavelet transform for compatibility with our compression algorithms.

Testing of the algorithm on a variety of images has included aerial views and other similar images from both infrared and electro-optical sources. Common to all these images were significant, and potentially important,

texture detail. We have found that the algorithm performs as well as or better than the same enhancement techniques performed in the pixel domain, and runs faster because filtering is performed only on the DC component of the coefficient space. This approach also allows us to easily integrate the enhancement capabiliity into our wavelet based compression algorithm to obtain better quality images following decompression.

We have also applied the algorithm to wavelet based image magnification. The result is magnified images with enhanced detail and without the negative effects of conventional pixel based magnification, e.g., jagged edges, pixelization, loss of detail, etc. This could be of particular benefit for electronic magnification and image analysis operations. The algorithms have been implemented in C under UNIX and as a MSWindows 32 bit DLL.

2.2 Feature Enhancement and Extraction Using Linear/Non-linear PDEs

At Summus, Ltd., we have also implemented the shock filter enhancement method of Osher and Rudin [1], and considered the methods of Oliker [2] and Lions [3]. These methods are based on calculating the solution of the equation:

$$u_t = -|\nabla u| F(\mathcal{L}(u)),$$

where $\mathcal{L}(u)$ is an edge detection or other curvature based operator, e.g. Laplacian, and $F(u)$ is a step function.

The solution of this equation for large t produces an image with sharp edges and reduced noise. Essentially, this method treats the image as a "blurred" representation of the original. Blurring is projected in time according to the diffusion equation shown above. By reversing the diffusion process, we can project toward the original image. The quality of enhancement depends on the choice of curvature based operator $\mathcal{L}(u)$. We have found that wavelet domain enhancement performs better on images that contain little noise, while shock filter enhancement produces better quality for images containing a large level of noise, such as quantization noise resulting from images that have been compressed to high compression ratios. The algorithm has been implemented in C under UNIX.

3 Review and Continuations

3.1 Completed Studies: Year I

In order to evaluate the utility of the wavelet-based oscillation measure for target detection, we used a series of thermal infrared images supplied by McDonnell-Douglas. These images consisted of targets hidden among clutter as well as targets that were in open terrain. The algorithm was able to distinguish targets with a P_D of 97%, with a P_{FA} of 6% with a testbed of 50 static images (10 taken from each sequence). There were dominant channnels in most of the images, where a wide bandpass filter in one of the n-dimensional channels was effective for discrimination. We caution that the testbed utilized is too limited to reach any definite conclusions concerning P_D and P_{FA}.

3.2 Directions for Continued Research: Year II

The current directions for research are to develop improved ATD/I/R algorithms by continuing the investigations associated with our Texas Instruments 'C40 code (delivered in August of 1995), and to incorporate advantages and insights gained by the activities reported in section 2. Particularly, we see the following tasks as critical to this endeavor.

- Reduction in the P_{FA} rate for static images through better use of the DC component of the coefficient space in signature determination and through the use of the feature enhancement techniques to effectively discern and describe man-made features.

- Extension of the static analysis techniques to target recognition and automatic target tracking in image sequences through an adaptive temporal modification of the wavelet-based oscillation measure. This will include sensitivity studies to dropped frames and jumps in scale due to zooming.

- Improve the target/clutter separation algorithm by experimenting with different wavelet filters, feature enhancement techniques, and non-linear PDEs. This includes wavelet transforms on non-rectangular lattices (with greater rotation invariance), invariant wavelet transforms and region-based wavelet transforms.

- Implement an integer version of the wavelet transform to speed up the algorithm.
- Develop fast segmentation algorithms based on combinations of wavelets and non-linear PDE feature extraction.

References

[1] S. Osher and L. I. Rudin, "Feature Oriented Image Enhancement Using Shock Filters," in *SIAM Journal of Numerical Analysis*, Vol. 27, No. 4, pp. 919–940, 1990.

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[3] L. Alverez, F. Guichard, P. Lions, J. Morel, "Axioms and Fundamental Equations of Image Processing," in *Arch. Rational Mech. Anal.* 123, Springer-Verlag, pp. 199-257, 1993.